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A Housing Energy Management Program

Report

Energy Ontario

REPORT ON THE ENERGY MANAGEMENT INSTALLATION AT 375 BLEECKER STREET

Project undertaken jointly by the Ontario Ministries of Municipal Affairs & Housing and Energy under the Community Energy Management Program (C.E.M.P.).

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A. EXECUTIVE SUMMARY AND RECOMMENDATIONS

1. An experimental computerized energy management system for control of space heating and ventilation was retrofitted to a high rise electrically heated apartment building.

2. The performance of the experimental energy management system was evaluated by comparing the experimental building to a similar building with a standard control system.

3. The performance of the experimental energy management system was also evaluated by comparing the experimental building to its own operating history prior to installation of the experimental system.

4. Both system evaluation techniques showed that the computerized system yielded about a 15% energy savings as compared to an existing control system.

5. The payback period for the system, based on 18 months of operating experience, is about 4.5 years.

6. The installation cost of the system was about $150 per suite. The operating cost is about $2 per suite per month. The resulting electricity cost savings are about $4.77 per suite per month.

7. Most of the energy savings achieved seem to be a consequence of limiting the energy supplied to each suite to the extent that tenants close their windows in the winter.

8. Check metering installed by Ontario Hydro throughout both the experimental building and the reference building permitted detailed energy analysis of the building by type of load.

9. As a result of practical operating experience, it was determined that any future such systems should incorporate domestic hot water monitoring, remote adjustment of load control setpoints and tamper monitoring of all computer override mechanisms.

10. In order to provide adequate space temperatures for tenants, it was found that the average suite bathroom exhaust air temperature must lie in the range 23°C to 24°C. Occasional dips in the average suite bathroom exhaust air temperature to 21.5°C were found to be tolerable.

11. Some complaints were received from tenants who desired suite temperatures substantially above the minimum temperatures specified by city bylaws.

12. The energy savings attributable to ventilation control were found to be a significant component of the total energy savings. The extent of these savings is limited by the need for odor suppression.

13. The system start-up procedure was found to be critical. It was found that the initial operating strategy ought to be one which optimizes load management. As tenants become acclimatized to reduced energy supplies, more

emphasis can be placed on energy conservation. Reduction in average energy supplied to tenants should take place very slowly, preferably being introduced gradually over many months.

14. In any future similar installation, wiring should be simplified to minimize the cost of fixed price contract maintenance.

B. BACKGROUND

1. In mid-1977, ADMIC Controls approached the Ministry of Municipal Affairs and Housing with a proposal to install energy cost saving equipment in a major electrically heated building owned by the Ontario Housing Corporation. On the recommendation of the Ministry of Municipal Affairs and Housing, two adjacent architecturally identical 327 suite all-electric apartment buildings with identical orientation, similar wind exposure, same management and similar tenancy were selected to evaluate the performance of the proposed ADMIC system as precisely as possible. In one building (375 Bleecker St.) the proposed ADMIC system was installed to control ventilation and suite heating, while the other building (325 Bleecker St.) was left unchanged. Ontario Hydro installed metering equipment in both buildings to monitor the performance of the control system, so that the energy consumption and peak demand in both buildings could be compared objectively. The Ontario Hydro metering equipment allowed separation and calculation of the suite heating, suite non heating, domestic hot water and common area loads particular to each building. (See Appendix A).

2. The energy consumption for these buildings over the four years prior to the ADMIC installation were averaged and compared on a month by month basis, to show that the buildings did in fact behave in a similar manner. (Table 1, Appendix B). A small systematic difference

between the buildings was found, which was partially due to a recreational load in one building, which was not present in the other building.

3. Installation work at 375 Bleecker Street commenced in February 1979 and was essentially completed by the end of August 1979. In the following three months the system was debugged and defects in existing suite heating equipment, which became apparent as a result of the ADMIC installation, were repaired. The system was working as anticipated by December 1979. January 1980 was the first month when meaningful data about the building performance was gathered.

4. This report is based on:

   a) The energy consumption of 325 Bleecker Street and 375 Bleecker Street as metered by Ontario Hydro.

   b) The ADMIC Control System setpoints and the building performance as monitored and logged by the ADMIC Central Control and Monitoring System. (This data is summarized in Appendices D,F,G,J).

   c) The Toronto Hydro Energy bills for 325 and 375 Bleecker Street.

   d) ADMIC's experience at dealing with various engineering, adjustment and human problems which had to be addressed to make the system fully operational and optimum in performance.

5. The purpose of this report is to describe the ADMIC System as installed at 375 Bleecker Street with reference to:

   a) The performance to date

   b) The electricity cost savings resulting from the installation

   c) Any recommended changes or additions to the system.

   d) The application of the system to other similar buildings.

C. SUITE HEATING CONTROL

Introduction

1. It was recognized at the onset that the cost of energy at 375 Bleecker Street could be significantly reduced by:
   a) Lowering the average suite temperature.
   b) Lowering the peak power demand.
   c) Reducing the amount of ventilated air during the heating season.

2. Prior to the ADMIC installation, the heating in each suite during the heating season (September 15th to June 1st) was controlled solely by the tenant through a local thermostat. Since most tenants are not energy conscious, particularly if they are not paying for the energy used, that control arrangement has the following drawbacks:
   a) Suite temperatures can be set much too high
   b) Thermostats are set high while, at the same time, the windows are opened, allowing cold air inside.

3. A mathematical analysis of Toronto weather data conducted by Dr. J. Urbaniak and Dr. C. Rhodes indicated that at least 15% of the heating energy of an apartment building can be saved if the average inside temperature is reduced by $3^{o}F$. In addition, further calculations by Dr. Urbaniak showed that a reduction of inside temperature by $3^{o}F$ at 375 Bleecker Street would result in a reduction in peak electricity demand of approximately 70 KW.

4. If the inside temperature is allowed to drift downwards a few degrees during transient drops in the outside temperature, when the demand for heating power is very high, then the peak power demand may be reduced significantly. The long thermal time constant of the building prevents the inside space temperature dropping excessively during short transient peak demand periods. If the unusually high demand persists for more than a few hours, the building starts to cool, an alarm is tripped, and the electricity demand setpoint must be raised. A major shortcoming of the 375 Bleecker Street installation is that there is no remote control of the demand setpoint. Changing the setpoint requires a site visit, often in the middle of the night. ADMIC has proposed to the Ministry of Municipal Affairs and Housing that this problem be rectified by integrating remote peak demand control into the ADMIC system.

5. Another area where savings in the cost of energy for suite heating can be realized is in the control of ventilation. This subject is dealt with in detail in the latter part of this report.

Control Strategy

1. The basic control strategy is to limit the amount of heat supplied to each suite in accordance with the outside air temperature, exhaust air temperature and load shedding considerations. This strategy is realized by using contactors to control the duty cycle of the space heating power supplied to each suite. A large number of contactors with staggered operating cycles are used, so that the total space heating power in the building remains approximately constant over a cycle period.

   The ADMIC installation at 375 Bleecker Street uses one multipole contactor to control 2, 3 or 4 suites. Suites are assigned to contactors such that the total load per contactor is approximately equal. The duty cycle of each contactor is staggered with respect to the duty cycle of all other contactors within that heating zone. The contactors are controlled by cycler-shedder modules located in an ADMIC Remote Terminal.

   The aim of the system is to provide a mechanism for indoor/outdoor control similar to that used in large efficiently operated hydronic buildings. Further refinements and improvements to this indoor/outdoor control incorporate:

   a) Adjustment of the indoor/outdoor control curve according to the exhaust air temperature to compensate for wind chill and solar heat gain.

b) Adjustment of the indoor/outdoor control curve to reduce the suite heating power during temporary periods of peak power demand.

The control strategy involves keeping the exhaust air temperature of the suites one to two degrees Celsius above the required legal minimum. This strategy minimizes complaints, and provides some allowance for dropping suite temperature during transient demand peaks.

Zoning

1. The heating loads in the building were divided into three different zones as follows:

   a) Bottom zone - The bottom eight floors, divided into 32 loads of approximately 22 KW each.

   b) Upper East zone - All floors above the 8th on the east side of the building, divided into 32 loads of approximately 16 KW each.

   c) Upper West zone - All floors above the 8th on the west side of the building, divided into 32 loads of approximately 17 KW each.

The upper east and west zones were selected to take into account solar and wind exposure differences. The bottom zone was necessitated by load size equalization. Within each zone the suites were arranged into groups of 2, 3 and 4 per contactor, such that the total load of each group was approximately equal. As noted above, this grouping resulted in 32 loads per zone, so that each load represented approximately 3% of the total suite heating

load per zone. For the purpose of smooth control, it was not desirable to have less loads per zone.

Start-up

1. When installation was completed and the suite heating placed under ADMIC control, a number of start-up problems were encountered.
   a) Since this was an experimental rather than a "production" building, provision was made for rearranging the wiring to permit arbitrary reassignment of contactors by zone, which would not have been necessary in an ordinary installation. This provision resulted in extra wiring complexity, which took two weeks to debug.
   b) After the wiring was fully debugged, 58 tenant suite heating complaints remained. Of these about 10 were found to be due to defective ceiling cord heating elements, defective in-suite circuit breakers, thermostats etc. For the remaining 48 suite heating complaints no corresponding system defects were found. Some closet breakers were found in an off position. It was obvious that many of these breakers had been off for a number of years (e.g. circuit breakers were painted over etc.) The fact that they were not previously a source of complaints indicates the building was previously overheated so much that a suite with a non-operational

heating circuit was heated by all its neighbours. A major source of complaints not due to system defects was related to cold floors. In these buildings the heating is via ceiling cord radiation. A substantial portion of the heat in each suite comes from the floor. This heat originates from the ceiling radiant heating of the apartment below. If that suite has its heat off (e.g. the suite is unoccupied or the resident is in bed or absent), then the suite above it is cold. Prior to the installation of the ADMIC System, when this condition existed, the ceiling cord heating of the upper suite simply ran longer to make up the difference. That extra operation was not possible with the ADMIC System. All residents had to be advised to leave their thermostats set at 70°F so as not to inconvenience the resident above them.

The majority of the remaining complaints resulted from residents' expectations of as high space heating temperatures as existed in the past.

c) The ground floor was found to be non-symmetrical with the rest of the building (i.e. the factors which influenced heat loss from the ground floor suites were signigicantly different from those influencing heat loss from suites on other floors). After some operational experience, the ground floor suites were taken off the control system at the request of the site

management. If the low voltage wiring is to be reconfigured, ADMIC would recommend double cycling the ground floor contactors rather than bypassing them.

Two other special cases developed. The first concerned the suite immediately above the superintendent's suite. The superintendent's suite is immediately above the boiler room and receives so much "free heat" from the boiler and domestic hot water storage tanks that its living room heating circuit seldom operates. Consequently, the suite above the superintendent's suite was found to be chronically cold, and had to be taken off the system. Similarly, one of the suites on the third floor was temporarily taken off the system when necessary electrical repairs were not carried out promptly. When this suite was returned to system control, the tenant complained and subsequently this suite was also kept off the system for the remainder of the heating season. This suite was restored to automatic control in the following heating season.

d) Once the above problems were resolved the building started to perform in the manner anticipated.

Indoor/Outdoor Control

1. Energy bills from the four years prior to installation of the ADMIC System were analyzed to establish the historic indoor/outdoor operating curve. This histor-

ical operating curve indicates the average KW heating power required by the building to maintain an acceptable suite temperature as a function of the mean outdoor temperature for each billing period. The operating curve also indicates the "number of heating loads" equivalent of the heating power on the basis of 55 KW per load, which is the average power equivalent of enabling one load in each of the three zones (see Zoning). The calculations to establish this curve are shown in Appendix C, and the graph of the curve for 375 Bleecker Street is given in Appendix D.

2. The initial or historical operating curve represented the initial condition of the building in terms of heating energy consumption, which had to be improved on (i.e. by shifting the curve downward and to the left) via suite heating control. A "target" operating curve (Appendix D) was established on the basis of the energy usage savings that could be expected from conversion to individual metering in this building, i.e. a 2213 KWh per suite annual deduction from the original curve. The basis for using 2213 KWh per suite as the target savings, and the necessary calculations to arrive at this curve, are shown in Appendix E. The procedure then was to begin suite heating control at the historic operating curve, and approach the target curve by controlled stages. The duty cycle of the suite heating cycler/controller was set according to the original curve, then progressively reduced

for any given outside air temperature, while monitoring any change in the exhaust air temperature. When the exhaust air temperature (i.e. the average suite temperature) dropped to 22°C, the curve was backed up slightly. The final operating curve for the number of loads enabled, or heating power supplied to the suites as a function of outside air temperature, is shown in Appendix D. Corresponding to this curve is a "look-up" table (Appendix F-1) stored in the memory of the Central Station computer to enable the required number of loads.

With hindsight, the strategy for establishing the operating curve would be different. Tenants were found to be extremely sensitive to small long-term variations in exhaust air temperature, but almost insensitive to short-term dips in exhaust air temperature. This observation is especially true for tenants who have been long-term residents of a particular building.

A better operating strategy, which yielded a much better payback after its implementation in December 1979, was to strike a compromise between optimum operation and tenant expectations as far as long-term average exhaust temperature was concerned. By keeping the exhaust air temperature above the legal minimum, short-term drops could be accommodated.

By regulating these short-term drops to be coincident with peak demand periods, remarkable peak demand electricity cost savings were achieved. This improved operating strategy greatly reduced tenant complaints

associated with the space temperature reduction in the building. There remained a hard core of dissatisfied tenants who wanted temperatures way above the legal minimums. These tenants could not be satisfied except by bypassing the ADMIC Control System for their individual suites.

3. It was found experimentally, as the number of loads to be cycled was reduced from the original operating curve, that the suite exhaust temperature was almost independent of the amount of heating power over a fairly wide power range. We believe that as less heat energy was supplied, tenants closed their windows to compensate. We believe that much of the savings realized by the ADMIC System were a result of the System encouraging the tenants to close their windows during the winter. Some savings were achieved by reducing the average suite temperature slightly, but it appears these savings were small compared to the savings resulting from tenants closing their windows. To verify these conclusions, it would be necessary to do precision temperature measurements in the referenced building. We do not have any sufficiently accurate data on the suite exhaust temperature prior to the ADMIC installation in the control building for comparison purposes. (The exhaust air temperature sensors were recalibrated to compensate for lead resistance during the installation of the control

wiring. Unfortunately, in the process the exact relationship between before and after calibrations was lost).

4. The duty cycle of the suite heating control for each zone is also modulated according to the exhaust air temperature. For the 1979/80 season, this control was implemented such that, should the exhaust air temperature drop below 21.5°C, the number of loads enabled is increased by an amount equivalent to a 2°C drop in outside temperature. Similarly, an increase in exhaust temperature to 23.5°C would signal the computer to decrease the number of loads corresponding to a 4°C increase in outside temperature on the operating curve. This offset control of the suite heating temperature was incorporated in the control system to allow for heat loss variation between zones, and to take into account such non-outside temperature variables as solar heat gain and wind chill. The "look-up" table for exhaust air temperatures are very stable, as indicated in Appendix G.

5. For the 1981/82 season the "exhaust air temperature offset" control was readjusted to in effect raise the setpoint temperature of the exhaust air slightly (from 22.5°C to 23.5°C). The offset table corresponding to this readjustment is also given in Appendix F-2 (under column labelled "1980/81"). Since this change was effected, together with a slight adjustment of the indoor/outdoor temperature control curve (Appendix F-1), there have been virtually no complaints of cold suites.

6. The operating curve is also offset on the basis of peak power demand. The ADMIC System monitors the number of loads shed by the GenTec peak demand controller and offsets the effective operating curve accordingly, to reduce suite heating power during periods of peak load. This feature was incorporated into the system after the first three months of heating season operation. In November 1979, it was noted from Hydro metering data, that substantial savings were being realized on energy consumption, but not what was anticipated on peak demand savings. One reason for this lack of performance was the difficulty of establishing an optimum setpoint for the GenTec load shedder. It was observed that during a cold snap there was a large demand simultaneously for suite heating and domestic hot water. On the basis that tenants were more sensitive to a shortage of hot water than to a temporary reduction in suite heating, and taking into account the large thermal time constant of the reinforced concrete structure of the building, the computer was reprogrammed to in effect divert some of the suite heating energy to provide additional hot water during peak demand periods. This feature allowed a reduction in the GenTec load shedder setpoint, resulting in a much improved load factor and better demand savings. The "look-up" table relating the GenTec output to the operating curve is shown in Appendix F-3. The consequential distribution of suite exhaust air temperatures is shown in Appendix G.

GenTec Setting

The initial GenTec settings were based on:

a) The average summer load of 373 KW, as determined from historical data, plus

b) the load from the target operating curve (reflecting the 2213 KWh per suite savings) corresponding to the lowest mean daily temperature for the month.

After the building thermal storage program was incorporated into the system in November 1979, it was found that the GenTec settings determined in this manner were satisfactory. In the 1980/81 heating season the GenTec settings had to be raised slightly, probably due to increased ventilation and colder weather.

Average Exhaust Air Temperature

1. Appendix G shows the distribution of exhaust air temperatures at 375 Bleecker Street, based on data logged by ADMIC equipment in the period of January 3 to May 29, 1980. In this period the exhaust fan ran at either half speed or full speed, but was never completely off. Some of the coldest days of that period (e.g. January 30, March 31) were included in our sample. The results graphed in Appendix G show that:

   a) The exhaust air temperature in the January - May 1980 period never dropped below 21.0^{o}C and fell

below 21.5°C less than 2% of the time.

b) The exhaust air temperature was maintained fairly constantly (84.5% of the time) in the 23.0° to 24.0°C range.

In this same period Mr. Robert Marshall of the Ministry of Municipal Affairs and Housing did numerous spot check measurements with a precision fast reacting portable temperature probe. In verbal communications with Dr. C. Rhodes of ADMIC, Mr. Marshall indicated that he found the suite temperatures to be in the 21.0 to 23.0° C range. This data is consistent with ADMIC's measurements, since the exhaust air is drawn from the top of the suites and some stratification within the suites is expected.

2. The above data confirms that the ADMIC System maintained average suite exhaust air temperature at or above the setpoint temperature of 22.5°C. Since some suites are colder than others, the average was kept slightly above the desired minimum suite temperature. As described earlier under the heading "Indoor/Outdoor Control", ADMIC raised the exhaust air temperature setpoint to approximately 23.5°C at the beginning of the 1980/81 season. The exhaust air temperatures for the building logged by the ADMIC computer during the September 1980-May 1981 period show continuing tight control about the setpoint.

Energy Consumption Savings

1. As explained earlier in this report, the performance of the system prior to January 3, 1980 does not accurately reflect the benefits of the system due to adjustment problems and malfunctions in the electrical heating circuits.

2. Two methods were used in calculating the energy cost savings resulting from the ADMIC installation at 375 Bleecker Street during the 1979-80 heating season. One method used was to compare the performance of the control building with the reference building (325 Bleecker Street) and adjust the difference by the systematic difference between the two buildings, based on 1975 to 1979 Toronto Hydro historical billing data. The second method used was to compare the Ontario Hydro metering data for both buildings and thus avoid systematic difference arguments.

3. The calculations of energy savings by the first method and data of energy usage as reflected in Toronto Hydro monthly electricity bills for the period of January to May 1980 are contained in an earlier report, attached here as Appendix B. They indicate that for the months of January to May 1980, energy usage savings at 375 Bleecker Street totalled 303,768 KWh after adjusting for the systematic difference.

4. The energy usage data for the two buildings reported by Ontario Hydro are shown on a monthly basis in Appendix H-1 for the 1979/80 season, and in Appendix H-2 for the 1980/81 season. The following observations and conclusions can be drawn from this data for the 1979/1980 season:

   a) Suite heating energy usage was 297,912 KWh or 21.1% less at 375 Bleecker Street.

   b) Suite domestic energy usage was 25,700 KWh or 5.4% greater at 375 Bleecker Street. The building management reported that portable heating equipment and use of ovens as a means of supplemental heating are problems at 375 Bleecker Street. The small difference in suite domestic usage for May would appear to confirm this explanation. In all cases where tenant complaints were checked out, the temperature measurements recorded were above 20°C and ranged from 21°C to 24°C. Data logged by ADMIC temperature sensors as noted earlier in this report (page 20) confirms that the average suite exhaust air temperatures were maintained fairly constantly in the 23°C to 24°C range.

   c) Energy consumption of penthouse mechanical equipment (elevators, exhaust fans etc.) was 31.4% or 31,280 KWh less at 375 Bleecker Street. This energy consumption reduction is probably due to the savings realized by the speed reduction in

the intake and exhaust fan motors at 375 Bleecker Street.

d) Domestic hot water consumption at 375 Bleecker Street was considerably higher (97,220 KWh or 16.4%). The same Ministry of Housing report, mentioned on the previous page, noted that a higher delivery temperature at 375 Bleecker Street could account for this difference.

5. If the suite domestic usage is included as part of the heating energy supplied to the suites, the energy savings realized by the ADMIC Control System, based on the Ontario Hydro metering data, should be the sum of KWh difference in suite heating, suite domestic and rooftop mechanical equipment consumption. Adding these differences for January/May 1980, yields a KWh saving of 297,912 KWh + 31,280 KWh - 25,700 KWh = 303,492 KWh. It should be noted that this is very nearly the same figure (303,768 KWh) which was obtained by using the "systematic difference" method (paragraph 3 on page 21). The dollar savings equivalent, using 1980 Toronto Hydro rate of $0.0146 per KWh and including the 10% discount, is $3,987. On a basis of degree-days (base 18 C), the above energy savings would have been 472,275 KWh or $6,205, had the ADMIC system been operating properly for the whole of the 1979/80 season.

6. The space heating energy saving of 472,275 KWh for a

whole season, or 1,444 KWh per suite compares with 2,213 KWh per suite previously mentioned as the annual energy consumption savings to be expected from conversion to individual metering in all electric buildings.

7. The calculation of energy consumption savings for the complete 1980/81 season are shown in Appendix H-2 and summarized in Table 1 following, together with January/May 1980 savings for comparison:

   a) Suite heating energy was 542,422 KWh or 20.0% less at 375 Bleecker Street.

   b) Domestic usage was 60,160 KWh or 7.0% more at 375 Bleecker Street, probably for the same reasons as in 1979/80 (see para. 4 (b) on page 22.

   c) Penthouse mechanical equipment usage was 38,054 KWh or 23.8% less at 375 Bleecker Street. As in 1979/80, this was probably due to reduced or on-off operation of the main ventilation unit.

   d) Domestic hot water consumption was 14.6% or 159,722 KWh greater at 375 Bleecker Street.

8. Including suite domestic usage and rooftop mechanical consumption as part of the total suite heating energy supplied to suites (item 4 of Table 1) yields 1980/81 consumption energy savings realized by the ADMIC system of 519,866 KWh or 1590 KWh per suite. This represents 14.9% of the total energy supplied to the control

Table I

Energy Consumption Savings at 375 Bleecker compared to 325 Bleecker according to Ontario Hydro Metering data during Jan./May 1980 and Sept. 80/May 81.

	Jan./May 80	Projected to (1) complete 1979/80 heating season	%	Sept.80/ May 81	%
1. Suite heating (KWh)	297,912	463,592	21.1	542,422	20.0
2 Suite domestic (KWh)	-25,700	-39,992	5.4	-60,610	-7.0
3. Penthouse mechanical (KWh)	31,280	48,675	31.4	38,054	23.8
4. Total of items 1 to 3, or "heating energy supplied to suites"	303,492	472,275	15.3	519,866	14.9
5. Item 4 on per suite basis (Kwh)		1,447		1,590	
6. Value of item 4 at prevailing Toronto hydro rates (2)	$3,987	$6,205		$7,265	
7. Value of item 5		$18.98		$22.22	

(1) on basis of degree days, as explained in note 1 on page 20, or a factor of 1.556138.
(2) 1980 -$.0146/KWh, 1981 - $.0161/KWh.

building (compared to 15.3% achieved in 1979/80). Although 1980/81 KWh savings were higher than in the previous season (519,866 KWh compared to 472,275 KWh or 10% more) as a percentage of total heating energy supplied to suites, they were slightly down (14.9% from 15.3%) since 1980/81 was a colder season.

Power Demand Savings

1. The peak demand KW for both buildings for the months of January to May 1980, and September 1980 to May 1981 from Toronto Hydro billing data are given in Columns 1 and 2 of Appendix 1. The demand savings are estimated by taking the difference in demand of the two buildings and adjusting this amount by the systematic difference from the historical data. As calculated in Appendix 1 the demand savings are 1,049 KW for January to May 1980 and 1527 KW for September 1980 to May 1981. Based on the Toronto Hydro demand charge of $7.84 per KW in 1980 and $8.62 in 1981 and including the 10% discount, this amounts to $7,402 for May 1980 or $11,518 for the entire 1979/80 heating season (projected) (1) and $11,443 for the 1980/81 season.

(1) January 3 to May 29, 1980 degree-days: 2289.
September 15, 1980 to May 29, 1981 degree days: 3562.
The 1979/80 heating season was very close to normal on a degree-day basis.

2. The demand savings, while significant, were not what would have been possible had there been control of the domestic hot water.

Benefit Cost Analysis

1. Summary of energy cost savings:

	For January to May 1980	1980 Season (projected)	Sept.1980 to May 1981
Energy Consumption	$ 3,987	$ 6,205	$ 7,265
Peak Demand	7,402	11,518	11,443
Total Savings	$11,389	$17,723	$18,708

2. Cost for this installation to the Ministry was:

Equipment, Engineering, Installation:	$47,933.09
Monthly charges, first year:	6,000.00
Monthly charges, second year (from July 1, 1980)	9,112.92

Monthly charges in future years will be higher. However, if we assume that the net benefits of the installation will also increase in the same proportion due to higher energy costs, then the payback period of this installation based on the first two seasons of operation is

$$\frac{\text{Total initial cost}}{\text{Average annual benefits}} = \frac{47,933.09}{\frac{1}{2}\,(17,723-6,000 + 18,708 - 9,122.92)}$$

$$\frac{47,933.09}{10,659.04} = 4.5 \text{ years}$$

3. Since this was an experimental or "one-time" installation,

ADMIC equipment, engineering or "one-time" installation costs were somewhat higher than would be possible on a production model. Electrical sub-contract costs are likely to be more in the future.

When similar installations were effected in privately owned apartment buildings in the summer and fall of 1981, the costs were as follows:

Supply and installation of Equipment	$175.00/suite
Control, Monitoring, Maintenance & Phone Line	$2.00/suite/month

These installations included domestic hot water control, long term operating contracts with annual escalator clauses, and all the features outlined under the heading "Hindsight".

D VENTILATION CONTROL

Introduction

1. Energy losses via the ventilation system can be minimized by:
   a) reducing the amount of ventilated air when the temperature drops below a given setpoint
   b) monitoring the efficiency of the heat recovery system to detect any malfunction.

2. The ventilation control at 375 Bleecker Street was accomplished as follows:
   a) The initial installation included the rewinding of the exhaust and supply fan motors for two-speed operation. During the first heating season (1979/80) the ADMIC System reduced the speed of both fan motors to one-half speed when the temperature dropped below $12^{o}C$.
   b) For the 1980/81 season the ventilation control algorithm was changed so that during this period the main ventilation unit was cycled on/off by the ADMIC computer, according to a time and temperature schedule.
   c) ADMIC temperature sensors were installed to monitor the four air temperatures about the thermal wheel (outside air, corridor supply, suite exhaust and building exhaust). These temperatures and the

resultant calculation of thermal wheel efficiency were logged at the ADMIC's Central Station. An alarm was tripped if the thermal wheel efficiency dropped below 30%. The outside air sensor was mounted on the north side of the building. The suite exhaust sensor was mounted in the common suite exhaust duct. The corridor supply and building exhaust sensors were custom made 4 point duct averaging sensors diagonally mounted as far as possible from the thermal wheel.

Thermal Wheel Monitoring

1. Considerable energy losses can result from a failure or malfunction of the heat recovery system during the heating season, if the condition is not detected and corrected quickly. ADMIC's calculations show that about 220KWh of energy per 1000 CFM supply fan capacity will be lost during an average heating season day when the thermal wheel is not operative. For 375 Bleecker Street, where the air flow is 13,700 CFM at full supply fan speed, this energy loss would add about $45 per day to energy consumption costs, and could also result in significant additional demand charges if this energy loss occurs during a peak demand period. As noted above, ADMIC equipment can detect instantaneously any malfunction or breakdown of the system, so that corrective action can be taken

as necessary.

2. In addition to total failure, the efficiency of a thermal wheel deteriorates with accumulation of dirt and with air flow imbalance. The accumulation of dirt is a long term effect, which takes place over a year or more. Air flow imbalance is caused by changes in outside temperature, as well as mechanical changes within the building's ventilation system.

Half-Speed Fan Ventilation

1. It is difficult to state with any precision what energy savings benefits at 375 Bleecker Street during the 1979/80 season were directly attributable to ventilation control, because of the many unknown factors which affect the rate of heat loss in the building and the heat loss via the ventilation system, and because of the high proportion of clogged or shut bathroom ventilation units. Experimental results (presented in the attached Appendix J) show that there is a significant drop in thermal wheel efficiency with a decrease in outside temperature. This drop is almost certainly due to an imbalance in the air stream and the "chimney effect", as more fully explained in the attached technical Appendix J. The drop in thermal wheel efficiency (from around 70% at higher outside temperatures to about 40 to 50% when outside temperatures reach 10°C to 20°C) indicates that greater energy savings from ventilation control are possible than would be the case

if we assumed that the thermal wheel efficiency stayed at 70% during the winter season. These results also suggest the desirability of raising the efficiency of the thermal wheel by better balancing of the supply and exhaust air streams, which in effect was partly accomplished for the 1980/81 season by shifting to an on-off rather than a half-speed/full-speed control algorithm.

Odor Control and Fan Speed Scheduling

1. As part of its energy conservation effort, in the spring and summer of 1980 the Ministry of Municipal Affairs and Housing undertook a program of resealing windows at 375 Bleecker Street. The Ministry also engaged a contractor to report on the state of the air balancing at 375 Bleecker Street. In the process the following problems were discovered:

   a) Many windows were originally fitted with nylon runners, a high proportion of which were found to be worn out. Consequently, these windows had a history of leaking excessively.

   b) Only about 30% of the bathroom ventilation unit dampers were open. These dampers would only stay in the fully open or fully closed position. They could not be set at an intermediate position.

   c) Many ventilation units were full of accumulated dirt.

2. After some discussion Ministry of Municipal Affairs and Housing technical staff and site management decided to:

   a) Replace the defective window runners

   b) Vacuum out dirt from ventilation units

   c) Jam all suite dampers in the open position.

3. In the fall of 1980 the combination of better sealing of windows, most dampers being open and reduced ventilation led to serious odor problems in the building.

   In the 1979 heating season, suites were generally adequately ventilated by way of leaky windows. Even with the ventilation system operating at half speed the mechanical ventilation per suite, where it existed, was generally more than adequate because only about 30% of the suites were mechanically ventilated. With all the dampers open the mechanical ventilation per suite was inadequate and odors drifted from suite to suite. This problem was aggravated by improper duct sizing, which was not discovered until after the damper adjustments had been carried out.

   An indication of the seriousness of the problem is that with the fans operating at half speed the superintendent's suite on the ground floor continuously back drafted.

In the fall of 1980, at a meeting between the Ministry of Municipal Affairs and Housing, ADMIC and the site management, it was decided to operate the main ventilation units on a start/stop sequence rather than half-speed. A program of cycling fans on/off according to a time and temperature schedule was continued for the remainder of the heating season, as follows:

Temp. below -13°C - fans off
Temp. above 12°C - fans on
Temp. between -13°C and 12°C - fans operated according to a time-of-day schedule:

8 p.m.	- 7 a.m.	off
7 a.m.	- 9 a.m.	on
9 a.m.	- 11 a.m.	off
11 a.m.	- 2.30 p.m.	on
2.30 p.m.	- 4.00 p.m.	off
4.00 p.m.	- 7.00 p.m.	on

There were still occasional odor complaints associated with the longer fan off periods.

The only apparent approaches to upgrading the ventilation at 375 Bleecker Street are to:

a) Grade the ductwork so as to balance the building
b) Replace the exhaust damper mechanisms in every suite with fully modulating units.

Both approaches are so expensive as to be almost out of the question.

The alternative is to let the tenants close the dampers or block the grills themselves, as may have occurred in the past, so that every tenant makes his or her own compromise between mechanical ventilation and odor control.

The strategy that ADMIC would like to follow in the near future is to run the corridor supply fan at full speed, and control the speed of the exhaust fan to maintain maximum thermal wheel recovery efficiency. This strategy entails lowering the speed of the exhaust fan at low outside temperatures as the stack effect becomes more pronounced.

Energy Savings

1. Calculation of the theoretical minimum and maximum energy savings attainable with two speed fan control yield respectively 13,000 and 46,000 KWh per year per 1000 CFM supply fan capacity. These calculations are based on Toronto weather data and experimental data at 375 Bleecker Street, as well as at another installation (280 Wellesley Street) where ADMIC equipment controls building ventilation. The justification for these figures is developed in the attached Appendix J.

2. Based on the above figures, it is estimated that for the 1979 to 1980 heating season the minimum energy cost

savings directly attributable to ventilation control at 375 Bleecker Street were $5,119 or 29% of the total cost of the heating energy savings projected for the 1979/80 heating season. This calculation is shown in Appendix K. Note that this calculation implicitly includes the drop in the thermal wheel efficiency with temperature.

3. The savings resulting from on-off control of the main ventilation unit (in effect during the 1980/81 season) are difficult to calculate on a theoretical basis, but we would estimate that they were about 25% of total suite heating energy savings, based on the assumption that ventilation fans were on about 50% of the time and the ventilation system was functioning properly. The exact run time is not available as

   a) At that time ADMIC did not have a run time totalization program.
   b) Site personnel were frequently leaving the fans in the hand instead of the auto position.
   c) There is no readily available data re time above $12^{o}C$ and time below $-13^{o}C$.

E HINDSIGHT

With the benefit of 20-20 hindsight a lot of practical lessons were learned regarding the installation and operation of this type of energy management system. These lessons could be applied either to future installations or to any contemplated refit of 375 Bleecker Street.

1. Noise Suppression

The contactors used for breaking the individual suite heating circuits make a thump each time they open or close. The effective way of suppressing this noise is to mount the contactor box on a concrete wall which does not back on to a tenant suite, and to suppress the acoustic noise with fibreglass insulation.

2. Riser Wiring

In a riser which serves over 100 contactors and numerous monitoring points every wire needs to be separately colour coded and the junction count needs to be minimized. Otherwide numerous manhours are lost sorting out which wire is which. Precautions have to be taken to avoid ground loops and other electrical interference problems. Therefore use:

a) 25 pair #24 telephone cable

b) Shielded phone lines

c) Large size common power supply and ground wires

d) Install tap boxes on riser cable rather than bringing all conductors into contactor panels.

3. Conduit

Do not use vertical riser conduit except where wires pass through floors. Conduit adds immensely to cost with little benefit, since riser wires are all in a protected location.

4. Fan Control

Rewind only the exhaust fan motor for two speeds. The intake fan can only be used in the full on or full off states if air balance is to be maintained.

5. Zoning

At 375 Bleecker Street there was very little difference observed between the operation of the various zones. Therefore, in the future, operate with only one zone for both lower capital and operating costs, e.g. at 375 Bleecker Street reconfigure for 48 loads in a 34, 38, 38 KW repeating sequence.

6. Monitoring

At 375 Bleecker Street numerous operational problems were encountered due to site personnel overriding the ADMIC equipment, and ADMIC's lack of knowledge as to the exact

amount of domestic hot water in storage. Consequently, any new installation should incorporate:

a) Monitoring of the position of all Hand-Off-Auto switches.
b) Monitoring of all tank junction temperatures.
c) Monitoring of the load shedder output status.

7. Control

At 375 Bleecker Street numerous operational problems were encountered due to ADMIC's inability to control:

a) The total power into the building
b) The domestic hot water temperature
c) Proper maintenance and adjustment of the three-way valves.

ADMIC's inability to control these items caused many otherwise unnecessary site visits and caused lack of hot water on some occasions. In any future installation it would be better to control all these parameters.

8. Suite Exhaust Dampers

Based on the problems with odor control at 375 Bleecker Street, everyone would have been better off if the suite exhaust dampers had been left alone. In the future, repositioning of suite exhaust dampers ought to be addressed with much more caution.

9. At 375 Bleecker Street the ground floor control was overridden because of that floor's asymmetry. In the future the ground floor ought to be double cycled to alleviate this problem.

10. The offset of the operating curve, based on the load shedder output, is subject to dangerous oscillations unless specific measures are taken to prevent them. The most effective measure is to offset on the basis of average power rather than instantaneous power. Similar but less rapid oscillations are associated with offset on the basis of exhaust air temperature. These oscillations can be induced by incompetent site personnel adjusting the differential on the load shedding equipment. Also tampering with the load shedder setpoint can cause either too cold a building, or wasteful energy consumption by virtue of the interaction between the load shedder output and system operating curve. THEREFORE UNDER NO CIRCUMSTANCES SHOULD SITE PERSONNEL BE PERMITTED TO TAMPER WITH THE LOAD CONTROL SYSTEM.

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3. Report on Ventilation and Heat Recovery System Prepared by Aerodynamic Testing & Balancing Consultants for Ministry of Municipal Affairs and Housing (Location: 375 Bleecker Street, Toronto, Ontario)